Promoting Preschool Children's Math Learning through Technology Integration

Phil Vahey[a]
Ashley Lewis Presser[b]
Deborah Rosenfield[b]

[a] SRI International, 333 Ravenswood Ave, Menlo Park, CA 94025
[b] Education Development Center, Center for Children & Technology, 96 Morton Street, New York, NY 10014

Presented at the National Council of Teachers of Mathematics 2015 Research Conference, Boston MA.

Correspondence concerning this manuscript should be sent to
Phil Vahey, philip.vahey@sri.com

Abstract

We report on two randomized controlled studies that demonstrate developmentally appropriate ways of integrating technology into preschool classrooms to support teachers' classroom practices and preschool children's mathematics learning. One project is based on the Ready To Learn multi-year initiative and used existing transmedia resources in the creation of a curriculum supplement. The other project, Next Generation Preschool Math (NGPM), brought together researchers and game developers to design, develop, and evaluate a set of game-based mathematics iPad apps and hands-on materials. Both studies showed that when technology is thoughtfully integrated into existing classroom structures, and when PD that integrates pedagogy, content learning, technology training, and activity implementation is given to teachers, teachers can effectively use the materials and students can learn more mathematics than typically taught in preschool.

Acknowledgments

This research was funded by the National Science Foundation (DRL-1119118) and Department of Education (U295A1005). Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation or the Department of Education.

Background

There is growing recognition of the importance of early mathematics learning, and increasing awareness of the tremendous potential all children have to develop a broad range of quantitative thinking skills. Early mathematics achievement is a strong predictor of later school achievement, and this predictive power is even greater than the predictive power of early literacy achievement (Claessens, Duncan, & Engel, 2009; Duncan et al., 2007). The National Association for the Education of Young Children (NAEYC) and the National Council of Teachers of Mathematics (NCTM) have jointly called attention to the need for appropriate, challenging, and effective early childhood mathematics programs (2010). Yet most preschool teachers are not trained in early mathematics content, the developmental trajectory of young children's acquisition of mathematics skills, or teaching strategies to promote mathematics learning (Ginsburg, Lee, & Boyd, 2008).

Fortunately, research shows that developmentally appropriate instruction can significantly affect preschool children's mathematics knowledge (Ginsburg, Lee, & Boyd, 2008), and that teachers and caregivers can effectively support children's mathematics learning (Casey, et. al., 2008; Kersch, Casey, & Mercer Young, 2008; Wolfgang, Stannard, & Jones, 2001). Our research is based on the premise that preschool teachers, when provided with high-quality materials and professional development, can support the development of young children's mathematics knowledge.

Our research also is based on the premise that digital technology, when used in a developmentally appropriate way, can assist teachers in increasing children's mathematics learning. While the use of technology in early childhood education settings has been controversial, resulting in a relative lack of knowledge about how to best use technology in the Pre-K environment (Davidson, Fields, & Yang, 2009), policy and research suggests that technology can provide unique opportunities for learning, even for very young children (Couse & Chen, 2010; Daugherty, Dossani, Johnson, & Oguz, 2014). Particularly productive opportunities can be found in the areas of *joint media engagement*, in which more expert peers and teachers scaffold the use of digital tools for learning in a collaborative setting (e.g., Clements & Sarama, 2003; Reiser, Tessmer, & Phelps, 1984; St. Peters, Huston, & Wright, 1989). The studies we present below add to the field's knowledge of how to effectively use digital technology to help young children learn important mathematics.

Overview Thematic Statement

This paper reports on two randomized controlled studies that demonstrate developmentally appropriate ways of integrating technology into preschool classrooms to support teachers' classroom practices and preschool children's mathematics learning. One project we call the Ready to Learn (RTL) project, the other the Next Generation Preschool Math (NGPM) project. In both projects, which we describe in detail below, we have developed technology-based materials to support math learning and curricular supports to integrate these materials into typical classroom routines. We have shown positive outcomes in both projects, including gains in children's math knowledge, as well as teachers' increased comfort and knowledge of early math content and of using technology to support learning.

There were significant similarities in these two studies. In both studies, we started with a curricular activity systems approach (Vahey, Knudsen, Rafanan, & Lara-Meloy, 2013), in which technology is integrated into coherent sequences of instructional activities, and these sequences are designed in accordance with the needs and constraints of public preschool programs. For example, both studies used non-digital activities—such as whole-class book reading and small-group hands-on activities—in addition to the digital materials. In both studies, the digital and non-digital materials were designed to address preschool math content standards and to employ common preschool activity structures, such as whole-class discussions during circle time and small-group work during center time. In both studies, the content was based on learning trajectories, which articulate progressively more sophisticated understandings of a concept that children typically experience over time (National Research Council, 2007). Teachers involved in both programs were provided professional development (PD) that integrated pedagogy, content knowledge, technology training, and materials use. Both studies used proximal assessments developed as part of each project to measure the specific target content, and both used the *Research Based Early Mathematics Assessment* (REMA) (Clements, Sarama, & Liu, 2008) as a distal outcome measure. Both studies conducted classroom observations and gathered information directly from teachers. Finally, both studies included classrooms in preschools that serve low-SES students in the New York and San Francisco Bay areas.

There also were significant differences between the two programs. RTL used interactive whiteboards and laptops, whereas NGPM used iPad tablets. RTL activities were built on preexisting transmedia resources, whereas the NGPM team conceptualized, designed, and developed a set of game-based mathematics iPad apps. The RTL intervention was one 10-week unit, whereas the NGPM intervention consisted of two 3-week units, for a total of 6 weeks. RTL used a supplement-based assessment (both the content and the context for the assessment items were aligned to the intervention), whereas NGPM used a content-based assessment (the content, but not the context, was aligned to the intervention). Finally, the RTL project conducted a large three-condition randomized control trial (RCT), whereas the NGPM project conducted a smaller two-condition block randomized control trial. Key similarities and differences are found in Table 1.

Study Characteristics	RTL	NGPM
Used learning trajectories	Yes	Yes
PD integrated pedagogy, content knowledge, technology, and materials	Yes	Yes
Used non-digital activities	Yes	Yes
Used common preschool activity structures	Yes	Yes
Used proximal assessments	Supplement-based assessment	Content-based assessment
Used REMA as distal assessment	Yes	Yes
Classroom observations	Yes	Yes
Teacher implementation data	Yes	Yes
Technology	Interactive whiteboards and laptops	iPad tablets
Media	Existing PBS transmedia	Developed for the study
Length of unit(s)	One 10-week unit	Two 3-week units
Randomized trial	3 conditions, 92 classrooms	2 conditions, 16 classrooms

Table 1: Similarities and differences between the RTL and NGPM projects

Ready to Learn Project

The Ready to Learn (RTL) initiative is a multi-year partnership between the U.S. Department of Education, the Corporation for Public Broadcasting (CPB), and the Public Broadcasting System (PBS). The primary aim of the partnership is to create early math and literacy learning experiences that leverage the unique capabilities of various technology platforms. These include new and emerging digital platforms, such as tablet computers, interactive whiteboards, and smartphones, in addition to well-established technologies, such as computers, video displays, and gaming consoles. As summative evaluators for the RTL initiative, we conducted a randomized controlled trial to explore how technology and educational transmedia resources can enhance prekindergarten math teaching and learning in preschools. The target population was children who may be at risk of academic difficulties due to economic and social disadvantages.

Description of Intervention

The RTL study was a 10-week experience for children in 92 low-income preschool classrooms in New York City and San Francisco. Classrooms were randomly assigned to one of three conditions:

1. <u>Transmedia Math Supplement condition</u>, including an Experience Guide for integrating into a pre-K classroom a set of videos, games, books, and hands-on materials related to the mathematics goals of the intervention, as well as an interactive whiteboard and laptop computers for classroom use, broadband Internet, technical assistance, and ongoing teacher coaching.
2. <u>Technology & Media condition</u>, including the above technology, technical assistance, and coaching, but no Experience Guide.
3. <u>Business-as-Usual condition</u>: in which educators were asked to continue their typical math and technology instruction and were not provided with any technology or guidance.

The first condition represents a well-supported joint media engagement experience, in which teachers are expected to implement a coherent set of learning activities. The second condition reflects preschool teachers' typical experience with mathematics and technology integration, in which they receive a set of resources and technology with training on technology and minimal training and support for integration into their instructional routine. The third condition reflects the current state of preschool classrooms.

The Transmedia Math Supplement was centered around PBS KIDS videos and digital games, played on a select set of learning technologies (i.e., preschool-specific interactive whiteboards and laptop computers). The Supplement used a transmedia approach, focusing on familiar characters, settings, and narratives across different media formats, such as digital video and interactive online games. The Supplement also included non-digital materials, like books and foam shapes, and was designed to complement existing instructional routines, such as circle time and free-play centers. The research team developed the Supplement by drawing on existing research of early childhood math instruction and sequencing (Clements & Sarama, 2009; Ginsburg, Greenes, & Balfanz, 2003), the team's understanding of typical early childhood math instruction from the Year One Context Studies (EDC & SRI, 2011) and 2012 Preschool Pilot Study of PBS KIDS Transmedia Mathematics Content ("2012 Preschool Pilot Study") (EDC & SRI, 2012), and existing research on successful technology integration in early childhood classrooms (e.g., McManis & Gunnewig, 2012). The target math skills included counting, subitizing, and recognizing numerals; recognizing, composing, and representing shapes; and patterning.

Research Questions

The study explored children's learning, teachers' beliefs, and the implementation of a technology-based curriculum supplement, and sought to answer the following research questions.

1. What is the impact of the Transmedia Math Supplement and Technology & Media experience on young children's mathematics learning?
2. What is the impact of the Transmedia Math Supplement and Technology & Media experience on teachers' attitudes and beliefs about early mathematics education and about using technology and media to support mathematics learning?
3. To what extent do teachers in the Transmedia Math Supplement group implement the curriculum supplement with fidelity?
4. What are the successes and barriers, if any, that teachers in the Transmedia Math Supplement group encounter while implementing the curriculum supplement?

Methodology

We collected a range of data from participating preschools. A random sample of children within each classroom (n=966) completed pre- and post-measures of mathematics knowledge, using both a standardized assessment and a researcher-developed assessment. Teachers completed pre- and post-surveys about their comfort teaching math and using technology to support math instruction. Teachers and coaches completed weekly logs about the use of technology, media, and, for those in the Transmedia condition, the curriculum supplement in classrooms, as well as the types of supports teachers required to implement the materials. Finally, coaches completed teacher observations to assess the fidelity of implementation of the curriculum supplement and the quality of instruction in all study classrooms.

Trained assessors conducted pre and post individual assessments with children using the *Research Based Early Mathematics Assessment* (REMA short form) (Weiland et al., 2012) and a *Supplement-Based Assessment* (SBA) developed by the research team. The REMA served as a valid and reliable standardized assessment of children's math skills, and included 19 items targeting recognition of number and subitizing, shape composition, and patterning. The SBA contained 20 items, and similarly targeted children's understanding of counting, number recognition, and subitizing; shapes; and patterning. It was aligned with the content of the PBS KIDS Transmedia Math Supplement. (For a fuller description of these measures, see Pasnik & Llorente, 2013.)

Teachers in all three conditions completed a teacher survey prior to the professional development at the start of the study and then again at the end of the study. The teacher survey used in this study was an iteration of the survey administered during the 2012 Preschool Pilot Study (EDC & SRI, 2012), and included questions about beliefs, attitudes, and practices around mathematics and around technology use and integration. The Early Math Collaborative at the Erikson Institute developed the questions about beliefs, attitudes, and practices around mathematics (McCray & Chen, 2012), and the RTL research team developed the questions about technology use and integration, based on literature reviews and a review of relevant surveys. The pre-survey also included demographic questions about the teachers, and the post-survey contained questions about experiences during and after the study.

Four integrated data collection activities were used to document the implementation of mathematics teaching and learning activities and to describe the contrasts between the Transmedia Math Supplement and the Technology & Media conditions. These comprised weekly teacher logs, weekly coach logs, fidelity observations, and quality observations. Classroom logs were completed by teachers in all three conditions, coach logs were completed by coaches supporting teachers in the Transmedia Math Supplement and the Technology & Media conditions, and fidelity observations were conducted in the Transmedia Math Supplement classrooms. Quality observations were conducted in 18 classrooms, split evenly among the three conditions.

Findings

Summary: Our results indicated positive gains for children and teachers who participated in the intervention, as well as general implementation of the Supplement with fidelity.

Research Question 1: What is the impact of the Transmedia Math Supplement and Technology & Media experience on young children's mathematics learning?

Children who participated in the Transmedia Math Supplement intervention improved significantly in their understanding of key early mathematics skills essential for early school success as measured by the SBA, as compared to the Technology & Media children (1.43 points, $g = .22$, $p<.001$) and the Business-as-Usual children (1.51 points, $g = .24$, $p<.001$). These same trends appeared on the REMA, but were marginally significant. The Transmedia Math Supplement children performed an average of 1.09 points better than both the Technology & Media children ($g = .15$, $p = .056$) and the Business-as-Usual children ($g = .15$, $p = .064$).

Impact Contrast	Coefficient	Std. Error	Hedges' g (Effect size)	p	Multiple Comparison Test*
SBA					
(1) PBS KIDS Transmedia Math Supplement vs. Business as Usual	1.51	0.302	0.24	<0.001	Significant
(2) PBS KIDS Transmedia Math Supplement vs. Technology & Media	1.43	0.288	0.22	<0.001	Significant
REMA					
(1) PBS KIDS Transmedia Math Supplement vs. Business as Usual	1.09	0.589	0.15	0.064	---
(2) PBS KIDS Transmedia Math Supplement vs. Technology & Media	1.09	0.571	0.15	0.056	---

*Note: thresholds for statistical significance adjusted for six pair-wise comparisons using the Bejamini-Hochberg False Discover Rate procedure.

Table 2: Summary of Transmedia Math Supplement impact estimates

Research Question 2: What is the impact of the Transmedia Math Supplement and Technology & Media experience on teachers' attitudes and beliefs about early mathematics education, and using technology and media to support mathematics learning?

Transmedia condition teachers reported significant changes in their confidence and comfort with early mathematics concepts and with teaching with technology, and also reported greater increases in their understanding of the concepts of number/operations and geometry relative to BAU condition teachers ($p<.05$). There was also a statistically significant increase in understanding of geometry concepts in the Transmedia condition teachers as compared to the Technology & Media teachers ($p<.05$).

Research Questions 3 & 4: To what extend do teachers in the Transmedia Math Supplement group implement the curriculum supplement with fidelity? What are the successes and barriers, if any, that teachers in the Transmedia Math Supplement group encounter while implementing the curriculum supplement?

Teachers generally implemented the Transmedia Math Supplement as intended, and addressed target mathematics skills more frequently than did teachers in the other two conditions. When teachers in the transmedia condition did make adjustments to activities, it was typically to break an activity into parts, shorten or extend an activity, or conduct a whole-class activity in small groups. Teachers also implemented the distinctive features of the Supplement, such as the warm-up and wrap-up activities, the video and book-reading pause points, and the instructional strategies emphasized in the professional development. Importantly, teachers did have challenges using digital resources and fitting activities into the daily schedule, which led to coaches offering frequent support. Notably, teachers in the Technology & Media condition received more on-site coach support than did teachers in the Transmedia Math Supplement condition, indicating that the guidance provided by the Experience Guide supported teachers in integrating technology into their regular classroom routines. Moreover, teachers in the Business-as-Usual group actually spent more time on target math skills than did the Technology & Media teachers, again pointing to the importance of the Experience Guide in making the technology and media useful tools for instruction.

Types of coaching support	**Transmedia Math Supplement**	**Technology & Media**
Provided support with media resources**	28.52%	55.25%
Provided support with math knowledge and skills and/or teaching strategies**	36.50%	48.47%

Co-led activities with the teacher(s)**	11.41%	28.47%
Observed instruction and provided feedback	57.63%	49.81%

**p<.001

Table 3: Differences in coaching support between Transmedia Math Supplement and Technology & Media conditions as reported in coach logs

Implications

These positive findings—children learning significantly more math and teachers expressing greater comfort with technology and confidence in their math teaching as a result of implementing the Supplement—support the notion that the thoughtful integration of well-designed digital resources coupled with adequate teacher supports can positively influence child and teacher outcomes.

The sharp, cohesive curricular focus of the Supplement stands in contrast to a common approach to technology integration, which tends to leave teachers to select resources piecemeal and on their own. The study results provide further evidence of the weakness of such an approach. Not only did learning gains not appear in the Technology & Media condition, but teachers in this condition reported spending less time on math instruction than did the teachers in the Business-as-Usual condition, suggesting that the difficult work of integrating technology actually interrupted or interfered with typical instructional routines.

Conversely, when teachers are prepared with the content knowledge and pedagogical experience needed to mediate children's learning with technology, children are able to make use of the learning opportunities available through engagement with digital media. Digital transmedia's potential to advance content-area learning for young children may therefore be of greatest value for those children who are most in need of academic support. Finally, the results demonstrate that recognizing teachers as the professionals they are is both a starting place and a commitment that must be sustained. Equipped with targeted materials and support for using those materials in their classrooms, teachers have the power to improve their practice and increase student learning.

Next Generation Preschool Math Project

We now describe the Next Generation Preschool Math (NGPM) project. The purpose of the NGPM project was to design and develop two research-based units that included both digital and hands-on, non-digital activities. These units introduce and help preschool children learn the important, but rarely taught, topics of subitizing and equipartitioning.

Description of the Intervention

In the NGPM project, a team that included learning scientists, preschool math education experts, assessment experts, and professional game developers designed a 6-week experience for preschools serving children from low-income neighborhoods. Preschool classrooms receiving the experience used a set of research-based physical manipulatives and innovative tablet-based games to support math learning in the areas of subitizing and equipartitioning. These materials were designed to be integrated into typical preschool classroom routines (e.g., circle time and center time), and teachers were provided with professional development, coaching, and a teacher's guide.

The design was based on a review of the preschool math literature and relevant learning standards for each content area, after which a learning blueprint was generated. The learning blueprint consisted of (1) a set of detailed learning goals, (2) tasks that address each learning goal for the instructional activities, (3) ways to vary difficulty of these tasks, (4) possible ways to scaffold the task, and (5) suggestions for the design of the activities. Each unit was designed to capitalize in a complementary way on both hands-on physical manipulatives and innovative tablet-based games, with a 5:1 ratio of physical manipulatives to digital games. The team went through an extensive process of designing, prototyping, pilot-testing, and revising until created a final set of eight digital mathematics games (four in each unit) and 40 hands-on games were created. The four games in each unit included two self-leveling (i.e., increasing in difficulty and providing teachers with feedback on student performance), one collaborative (i.e., two children play on one table at the same time), and one "sandbox" (i.e., free play) game type.

To prepare teachers to use our materials and activities, teachers in the treatment group attended a full-day professional development workshop before implementing the unit in the classroom. In this workshop, we focused on (1) the mathematics content, (2) typical difficulties children experience in learning the content, (3) methods for teaching the specific content, (4) a technology orientation, and (5) an overview of each digital game and non-digital activity. For the duration of the study, we provided each classroom a set of five iPad tablets—one for the teacher, and four for the children to use in a digital learning center—as well as all non-digital materials and books. Control teachers were provided the professional development and materials at the conclusion of the study.

Research Questions

The study focused on the preliminary impact of using the two NGPM units on preschool children's mathematics learning, specifically trying to answer the following main research questions:

1. Does experiencing the entire intervention (units 1 and 2) impact young children's performance on an assessment of NGPM content (mastery of subitizing and equipartitioning)?
2. Can the NGPM units feasibly be implemented in preschool classrooms?

In addition, we posed three exploratory research questions:

3. Does experiencing the unit 1 materials impact young children's mastery of subitizing, as measured by a subscore on the assessment?
4. Does experiencing the unit 2 materials impact young children's mastery of equipartitioning, as measured by a subscore on the assessment?
5. Does experiencing the intervention improve general mathematics knowledge (REMA)?

Methodology

The blocked randomized controlled study comprised 16 preschool classrooms matched into eight pairs by school-level demographic variables and randomized within each pair into either the treatment or control group. A blocked randomized design has the advantage of accounting for both observed and unobserved variables through randomization. Given the small sample size, it is recommended to create blocks and randomize within each one in order to maximize statistical power (Hedges, personal communication).

Data collected from children included two individually administered assessments, given both before and after the intervention. To account for any potential selection bias, 8–12 students within each classroom were randomly selected for testing. The *NGPM Assessment of Children's*

Mathematic Knowledge was developed as part of the NGPM project to assess young children's subitizing and equipartitioning learning. This assessment was developed because there is currently no standardized assessment or subscale that targets these skills specifically. The assessment was developed to measure the skills targeted in the program, but not to be aligned to the activities included in the program. The learning blueprint guided item development. The final set of questions was arranged in a flipbook format: One side contains instructions for assessors, and the other side displays relevant images that are presented, along with hands-on manipulatives, to children. This battery was pilot-tested with preschool children by assessors who were trained to be reliable at 95% with assessment protocols. The psychometric properties of the assessment were then examined in an IRT framework using Winsteps. Results from IRT analyses indicated that the battery had good reliability (.75 at pre-test and .76 at post-test), covered a wide range of item difficulty levels, and provided good coverage of the range of abilities represented in the study sample. We also used the REMA short form to determine whether the treatment and control group had baseline equivalence at the beginning of the study, and to determine if NGPM impacted overall mathematics achievement. (We hypothesized it would not in such a short period of time, and also because our intervention content was highly focused on skills not prevalent in the REMA.)

In addition, information was collected through classroom observations about how teachers implemented the activities, and information about the impact of the professional development and teachers' experiences using our curricular supplement were collected through teacher interviews and logs.

Findings

Summary: Results from this study indicate that experiencing the materials resulted in significant gains in children's learning of subitizing and equipartitioning, as compared to the control group; that teachers find these activities useful; and that teachers are able to integrate them into their classrooms to promote mathematics learning.

Research Question 1: Does experiencing the entire intervention (units 1 and 2) impact young children's performance on an assessment of NGPM content (mastery of subitizing and equipartitioning)?

There was baseline equivalence between the groups at the beginning of the study, and findings suggest the experimental group's post-test scores (M=59.69) were statistically different than the control group's (M=53.53) on the unit-specific content (subitizing and equipartitioning) when classroom-level pretest scores were statistically controlled (p=.026, effect size=.51). See Figure 1.

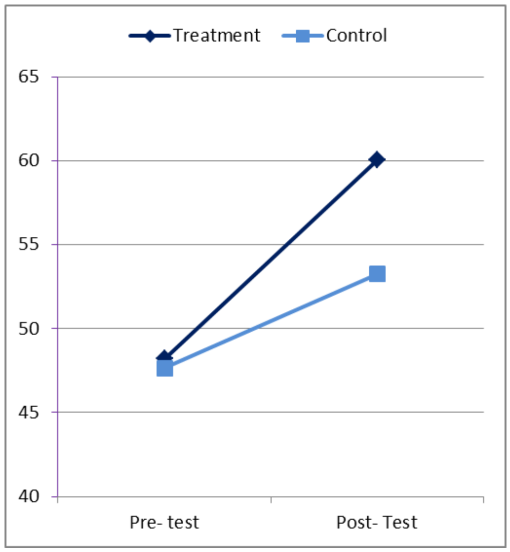

Figure 1: NGPM treatment children scored higher on the NGPM post-test than did the control group

Research Question 2: Can the NGPM units feasibly be implemented in preschool classrooms?

Implementation findings from classroom observations and teacher interviews suggest that teachers found the materials and activities useful, and were able to successfully integrate them in their classrooms to promote mathematics learning. In addition, a survey of preschool teachers who participated in the study showed an extremely high interest in the creation of additional materials.

Research Question 3 & 4 (exploratory): Does experiencing the unit 1 materials impact young children's mastery of subitizing as measured by a subscore on the assessment? Does experiencing the unit 2 materials impact young children's mastery of equipartitioning as measured by a subscore on the assessment?

There was baseline equivalence between the groups at the beginning of the study on both subitizing and equipartitioning subscales. For the subitizing subscale, findings suggest the experimental group's post-test scores (M=62.41) were statistically different than the control group's (M=55.07) when classroom-level pretest subitizing and general math scores were statistically controlled (*p*=.015, effect size=.69). For the equipartitioning subscale, findings suggest the experimental group's post-test scores (M=58.76) were marginally different than the control group's (M=51.32) when classroom-level pretest equipartitioning and general math scores were statistically controlled (*p*=.07, effect size=.43).

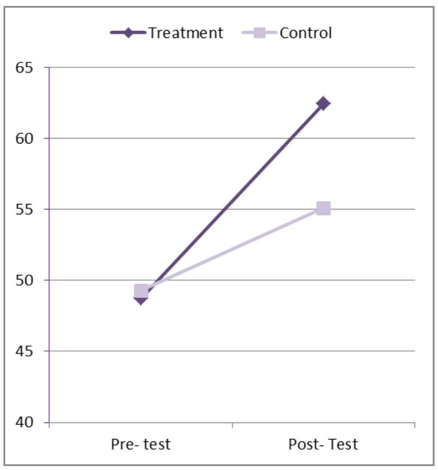

Figure 2a. NGPM children scored higher on the subitizing subscale than did control children

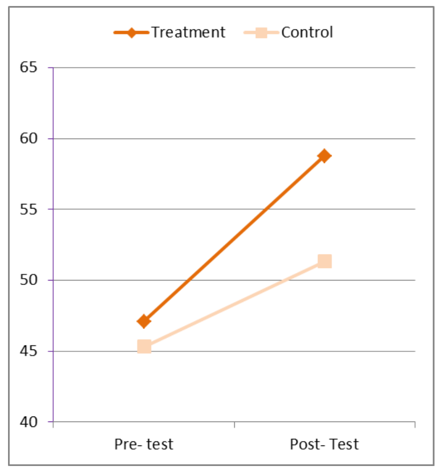

Figure 2b. NGPM children scored marginally higher on the equipartitioning subscale than did control children

Research Question 5 (exploratory): Does experiencing the intervention improve general mathematics knowledge?

These results did not show significant improvements in students' overall, global math learning. For the general math measure, findings suggest the experimental group's post-test scores (M=49.93) were not statistically different than the control group's (M=48.17) when pretest general math scores were statistically controlled (*p*=.138, effect size=.25).

We used the pre-assessment data to establish baseline equivalence between the groups (see RQ1), but did not expect to find significant changes in overall mathematics achievement, given the short duration and very specific content focus of our units.

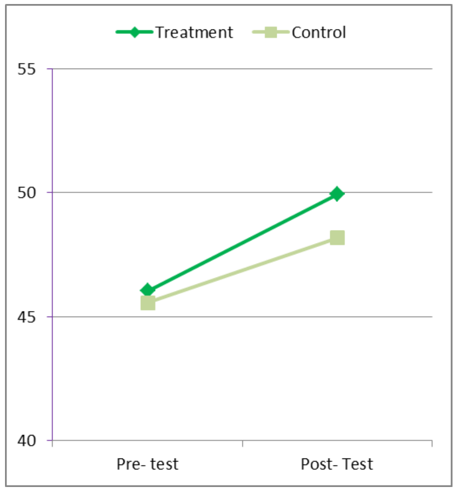

Figure 3: There was no difference between NGPM and control children on the REMA

Implications of the NGPM study

These results provide preliminary evidence that the 6-week experience improves preschool children's understanding of unit-specific content, and adds credence to our approach of selectively integrating tablet-based games into the preschool learning environment. These findings—that preschool children learn more unit content, and that the intervention can be feasibly implemented within a preschool setting—support the position that digitally-infused learning opportunities hold great potential for improving preschool children's mathematics achievement. In particular, our model of using a small number of tablet computers, as opposed to a 1:1 model, serves the purpose of integrating technology into existing preschool practices in a developmentally appropriate manner for this age group at a significantly reduced price. Tablets are a new technology that is becoming more and more ubiquitous, yet proper use requires the availability of quality digital activities that seamlessly fold into the preschool classroom setting. Teachers are more and more interested in using technology in the classroom, yet need guidance on how to do so effectively (Simon et al., 2013), to which our program's professional development and resources contribute. In addition to the availability of quality digital activities and the preparation of preschool teachers, it is important that these digital activities exist within a larger framework of learning that continues to value the importance of hands-on manipulatives, is enjoyable to preschoolers, and affects their preparedness for future mathematics learning.

Overall Implications for the Field

Taken together, these studies show that different technology-based approaches to preschool mathematics education can result in significant learning gains on important mathematical concepts. Given the relative lack of studies that show the effectiveness of technology use in education generally, these consistent findings contribute to the field in a number of ways.

1. These studies show that technology can be used to increase math learning in typical preschool classrooms that serve low-SES populations, even with relatively short interventions.
2. This is particularly important because math is rarely taught in preschool. Thus, there is an opportunity to dramatically improve young children's mathematics understanding through successful interventions designed for economically disadvantaged children that may mitigate those students' academic risk.
3. Further, the two studies used very different forms of technology: different hardware, different digital resources, and different math content. So it is not the case that there is one model of technology use that should be adopted. Instead, these studies show that a variety of uses of technology can increase student learning.
4. This does not mean, however, that *any* use of technology should be expected to lead to such gains. In fact, the Technology & Media condition of the RTL study negates this idea: When teachers are only provided technology-based materials and coaching without a clear and coherent framework for use, learning does not increase (even when technology use is the same), and is, in fact, hindered.
5. We *can* say that, when technology is thoughtfully integrated into existing classroom structures, and when PD that integrates pedagogy, content learning, technology training, and activity implementation is given to teachers, teachers can effectively use the materials and students can learn. This is consistent with prior research on curriculum activity systems.

Implications for Practice

These studies show that technology can lead to effective learning in preschool classrooms when used judiciously and in age- and developmentally-appropriate ways. To be used effectively, technology should be not considered like a field trip, where it is something children experience as a special event on rare occasions. Instead, we recommend the following:

- Technology should not replace non-technology activities; instead, technology and non-technology activities should be used together to leverage the strengths of each.
- As with all content, technology-based content must be integrated into a coherent learning trajectory.
- The technology should be integrated into existing classroom structures; while technology does provide the chance for new types of activities, genuinely new activity types should be introduced judiciously, as teachers are typically not willing to overhaul their entire classroom structure when technology is introduced.
- Teachers should be provided PD that integrates appropriate pedagogy, content learning, technology use, and activity use. Technology training alone is not sufficient to help teachers effectively integrate technology into their classrooms.

These research-based recommendations have the potential to help preschools and preschool teachers accomplish the tricky task of integrating technology into preschool children's learning environments in ways that are likely to benefit learning, rather than simply exposing children to technology.

Implication for Future Research

While these studies show positive gains, the studies are not based on long-term curriculum materials, and so it is not clear how this approach will scale to a full year (or longer) curriculum. There are questions related to the duration itself (for instance, do children remain engaged with the materials when they are in place for a full year?), as well as the content (do the approaches taken in these studies work for additional content, or are the findings dependent upon the specific content addressed?).

These studies also begin to elucidate how student collaboration can be positively affected by new technologies, but the focus of the studies was not collaboration. We hope that researchers focus on the unique ways in which technology can support young children in engaging in face-to-face collaboration. While technology-based educational games have traditionally been used to support individual practice, and there is much hype around hyper-personalization with technology, we instead see the promise of technology, especially for preschool children, in providing supports for collaborative activities. The NGPM project has taken an initial step in this direction, designing games in which preschool children collaborate while using iPad tablets. We believe that this is but a small first step, and that research will uncover new and innovative uses of technology to support young children in collaboratively investigating important mathematics content.

Our final hope for future research is to focus on the integration of mathematics with other core learning areas. Preschool teachers are under pressure to address a large number of standards (Brown, 2007), including content standards, such as literacy, math, and science, and socio-emotional standards, such as social awareness, relationship skills, and self-management. To ensure that teachers have time to teach mathematics, it will be incumbent upon mathematics educators to integrate mathematics content with other core learning areas. One area that this team is starting to consider is the integration of mathematics content with the promotion of *adaptive approaches to learning* (ATL), which include skills and dispositions conducive to learning, such as persistence, productive collaboration, and flexible problem solving. We note that ATL is best taught in the context of content-specific learning domains, and teachers have difficulty performing such integration themselves—however, certain ATL behaviors, such as persisting when tasks are challenging, collaborating with peers during learning activities, and trying different strategies when solving problems, are both aligned with new math content standards and can occur as a natural byproduct of engaging in collaborative and challenging mathematical activities.

References

Brown, C. P. (2007). Unpacking standards in early childhood education. *Teachers College Record, 109*(3), 635–668.

Casey, B. M., Andrews, N., Schindler, H., Kersch, J. E., Samper, A., & Copley, J. (2008). The development of spatial skills through interventions involving block-building activities. *Cognition and Instruction, 26*(3), 269–309.

Claessens, A., Duncan, G. J., & Engel, M. (2009). Kindergarten skills and fifth grade achievement: Evidence from the ECLS-K. *Economics of Education Review, 28*(4), 415–427.

Clements, D. & Sarama, J. (2003). Young children and technology: What does the research say? *Young Children, 58*(6), 34–40.

Clements, D.H. & Sarama, J.H. (2009). *Learning and teaching early math: The learning trajectories approach*. New York, NY: Routledge.

Clements, D., Sarama, J., & Liu, X. (2008). Development of a measure of early mathematics achievement using the Rasch model: The research-based early math assessment. *Educational Psychology, 28*(4), 457–482.

Couse, L. J. & Chen, D. W. (2010). A tablet computer for young children? Exploring its viability for early childhood education. *Journal of Research on Technology in Education, 43*(1), 75–98.

Davidson, M. R., Fields, M. K., & Yang, J. (2009). A randomized trial study of a preschool literacy curriculum: The importance of implementation. *Journal of Research on Educational Effectiveness, 2*, 177–208.

Daugherty, L., Dossani, R., Johnson, E. E. & Oguz, M. (2014). Using early childhood education to bridge the digital divide. *Rand Corporation*. Retrieved from http://www.rand.org/pubs/perspectives/PE119.html

Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., Pagani, L. S., Feinstein, L., Engel, M., Brooks-Gunn, J., Sexton, H. Duckworth, K., Japel, C. (2007). School readiness and later achievement. *Developmental Psychology, 43(6),* 1428–1446.

Education Development Center & SRI International (2011). *Year one context studies. A report to the Ready to Learn Initiative*. Waltham, MA, and Menlo Park, CA: Authors.

Education Development Center & SRI International (2012). *2012 Preschool pilot study of PBS KIDS transmedia mathematics content. A report to the CPB-PBS Ready to Learning Initiative*. Waltham, MA, and Menlo Park, CA: Authors.

Ginsburg, H.P., Greenes, C., & Balfanz, R. (2003). *Big math for little kids: Pre-kindergarten*. Parsippany, NJ: Dale Seymour Publications, Pearson Learning Group.

Ginsburg, H. P., Lee, J. S., & Boyd, J. S. (2008). Mathematics education for young children: What it is and how to promote it. *Social Policy Report: Giving Child and Youth Development Knowledge Away, 22*(1), 3–22.

Kersch, J., Casey, B., & Mercer Young, J. (2008). Research on spatial skills and block building in girls and boys: The relationship to later mathematics learning. In B. Spodak and O. Saracho (Eds.), *Contemporary perspective on mathematics in early childhood education* (pp. 233–253). Charlotte, NC: Information Age Publishing.

McCray, J. S., & Chen, J. (2012). Pedagogical content knowledge for preschool mathematics: Construct validity of a new teacher interview. *Journal of Research in Childhood Education, 26*, 291–307.

McManis, L.D. & Gunnewig, S.B. (2012). Finding the education in educational technology with early learners. *Young Children, 67*(3), 14-24.

National Association for the Education of Young Children & National Council of Teachers of Mathematics. (2010). *Early childhood mathematics: Promoting good beginnings.* Washington, DC, and Reston, VA: Authors.

National Research Council, Committee on Science Learning, Kindergarten Through Eighth Grade. (2007). *Taking science to school: Learning and teaching science in grades K–8.* Washington, DC: National Academy Press.

Pasnik, S. & Llorente, C. (2013). *Preschool Teachers Can Use a PBS KIDS Transmedia Curriculum Supplement to Support Young Children's Mathematics Learning: Results of a Randomized Controlled Trial. A report to the CPB-PBS Ready to Learn Initiative*. Waltham, MA, and Menlo Park, CA.

Reiser, R. A., Tessmer, M. A., & Phelps, P. C. (1984). Adult-child interaction in children's learning from Sesame Street. *Educational Communication and Technology Journal, 32*, 217–223.

Simon, F., Nemeth, K., & McManis, D. (2013). Technology in ECE classrooms: Results of a new survey and implications for the field. *Child Care Exchange, 35*(5), 68–75.

St. Peters, M., Huston, A. C., & Wright, J. C. (April, 1989). *Television and families: Parental coviewing and young children's language development.* Paper presented at the Society for Research in Child Development, Kansas City, MO.

Vahey, P., Knudsen, J., Rafanan, K. & Lara-Meloy, T. (2013). Curricular activity systems supporting the use of dynamic representations to foster students' deep understanding of mathematics. In C. Mouza and N. Lavigne (Eds.), *Emerging technologies for the classroom: A learning sciences perspective*, pp. 15–30. New York City, NY: Springer.

Weiland, C., Wolfe, C.B., Hurwitz, M., Clements, D., Sarama, J., & Yoshikawa, H. (2012). Early mathematics assessment: Validation of the short form of a prekindergarten and kindergarten mathematics measure. *Education Psychology, 32*(2), 311-333.

Wolfgang, C. H., Stannard, L. L., & Jones, I. (2001). Block play performance among preschoolers as a predictor of later school achievement in mathematics. *Journal of Research in Childhood Education, 15*(2), 173–180.